

**PHASE GRATING FOCUS MONITOR  
USING OVERLAY TECHNIQUE**

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**BACKGROUND OF THE INVENTION**

1. Field of the Invention

This invention relates generally to optical apparatus in semiconductor technology, and more particularly, to a test monitor for use in focusing an image on a semiconductor wafer.

2. Discussion of the Related Art

Typically, an optical system 30 (Figure 1) used for patterning photoresist 32 on a semiconductor wafer 34 comprises a light source 36, a mask or reticle 38 having opaque lines 40 and transparent portions 42, and a lens 44, the light from the light source 36 passing through the transparent portions 42 of the mask/reticle 38 through the lens 44 and to the photoresist 32, with light being blocked from reaching the lens 44 (and photoresist 32) by the opaque lines 40 of the mask/reticle.

As is well known, there is a need to position the wafer 34 at a proper distance with respect to the lens 44 so that images that fall on the photoresist 32 of the wafer 34 will be in the plane of best focus.

Generally, prior to actual fabrication of semiconductor devices, a test focus monitor in the form of for example a reticle is used as part of the overall system to achieve proper focus of the image on the wafer. An example of such a monitor is shown and described in the paper entitled "New Phase Shift Ratings For Measuring Aberrations", by Hiroshi Nomura, published by SPIE, dated February 27, 2001, which is herein incorporated by reference. Figures 2-4 herein show a monitor 50 configured as shown in Figures 3 and 5 of that paper. The monitor 50 is made up of a quartz base 52 which is transparent to light, and which has a plurality of parallel, opaque, spaced apart lines 54 on the base 52, the lines 54 having a first set of adjacent ends 55, and a second, opposite set of adjacent ends 56. The area between each adjacent pair of lines 54 is transparent to light and is made up of regions 58 which pass light therethrough without changing the phase thereof, and regions 60 which pass light therethrough which shift the phase of such light by 90° (the phase shifting caused by recesses 62 in the base 52—see Figures 3 and 4 and the above cited paper). Each of the lines 54 has a region 58 and a region 60 which are aligned along and on one

side thereof, and a region 58 and a region 60 which are aligned along and on the opposite side thereof. Each of the lines 54 has a region 58 on one side thereof opposite a region 60 on the other side thereof, these regions 58, 60 running from end 55 of that line to adjacent to the middle thereof, and furthermore, each of the lines 54 has a region 60 on the one side thereof opposite a region 58 on the other side thereof, these regions 60, 58 running from end 56 to adjacent the middle thereof.

Figures 3 and 4 are views similar to that shown in Figure 1, but incorporating the monitor 50 of Figure 2 as a part of the system 30. Figure 3 includes a sectional view of the monitor 50 taken along the line 3-3 of Figure 2, showing a cross-section of the upper area 50A of the monitor 50, while Figure 4 includes a sectional view of the monitor 50 taken along the line 4-4 of Figure 2, showing a cross-section of the lower area 50B of the monitor 50. As will be seen, with reference to the upper area 50A of the monitor 50 (Figure 3), moving the wafer 34 and lens 44 relatively together and apart causes the shadows 64A, 64B, 64C formed on the photoresist 32 of the wafer 34 (formed by the opaque lines 54) to shift (downward as the wafer 34 and lens 44 are moved relatively further apart). Meanwhile, with reference to the lower area 50B of the monitor 50 (Figure 4), moving the wafer 34 and lens 44 relatively together and apart causes the shadows 64D, 64E, 64F formed on the photoresist 32 of the wafer 34 to shift (upward as the wafer 34 and lens 44 are moved relatively further apart). The dotted lines 66 in Figures 3 and 4 indicate the traverse of the shadows 64A, 64B, 64C, 64D, 64E, 64F as the wafer 34 is so moved relatively toward and away from the lens 44.

These paths are plotted in Figure 5, and the intersections thereof indicate the best focus of the image on the wafer 34.

Figure 6 includes Figures 6A - 6F which are views taken along the lines 6A-6A, 6B-6B, 6C-6C, 6D-6D, 6E-6E, and 6F-6F of Figures 3 and 4. With the wafer 34 and lens 44 closest together as shown in Figures 3 and 4, Figures 6A and 6D show the simultaneous positions of the shadows 64A-64F on the photoresist 32 determined by the respective areas 50A, 50B of the monitor 50. With the wafer 34 and lens 44 so positioned relative to each other, the photoresist 32 is exposed to light from the light source 36 and is then developed to determine photoresist lines which corresponds to the positions of the shadows 64A-64F. As will be seen, the lines of Figures 6A and 6D are misaligned. As the wafer 34 and lens 36 are moved relatively further apart to an intermediate position as shown in Figures 3 in 4, Figures 6B and 6E show the simultaneous positions of the shadows 64A-64F on the photoresist 32 determined by the respective areas 50A, 50B of the monitor 50. Again, the photoresist 32 is exposed to light from the light source 36 and is then developed to determine photoresist lines which correspond to the positions of the shadows 64A-64F. As will be seen, the lines of Figures 6B and 6E are substantially in alignment. Then, as the wafer 34 and lens 44 are moved relatively further apart,

i.e., to their most far apart positions as shown in Figures 3 and 4, Figures 6C and 6F show the simultaneous positions of the shadows 64A-64F on the photoresist 32 determined by their respective areas 50A, 50B of the monitor 50. Again, with the wafer 34 and lens 44 so positioned relative to each other, the photoresist 32 is exposed to a light from the light source 36 and is then developed to determine photoresist lines which correspond to the positions of the shadows 64A-64F. As will be seen, the lines of Figures 6E and 6F are misaligned.

It will be seen that changing the distance between the lens 44 and wafer 34 causes the shadows 64A-64C to move further in and out of alignment with the shadows 64D-64F. The process of moving the lens 44 and wafer 34 relatively closer together and further apart, along with the corresponding exposure and development of the photoresist 32 accompanying each adjustment, is repeated until the lines formed in the photoresist 32 are substantially straight. This is illustrated in Figure 6 of the above cited paper.

While such an approach is useful, only a relatively coarse reading of focus is achievable. For example, with reference to Figure 6 of the above cited paper, only a small shift in the pattern from top to bottom is shown over a range of 400 nm of relative movement between the wafer 34 and lens 44. With device dimensions continually being reduced, there is a need to achieve a proper reading of focus within a much smaller range of lens-wafer relative movement, for example, 200 nm or less.

The Benchmark Technologies Incorporated Phase Shift Focus Monitor Test Reticle 100 (Figure 7) uses phase shifting to produce images which shift according to the magnitude of defocus. In this apparatus 100, a quartz body 102 which is transparent to light has thereon opaque, for example chrome, lines 104, 106, 108, 110 which define an outline 112 in the shape of a square. The body 102 also has thereon opaque, for example chrome, lines 114, 116, 118, 120 that define an outline 122 in the shape of a square, which is centrally positioned relative to and within the square 112. The regions 124 of the quartz body 102 allow light to be transmitted therethrough without changing the phase thereof, while the regions 126, recessed as described above, allow light to be transmitted therethrough while changing the phase thereof by 90°. It will be seen that with this configuration, each opaque line is positioned between phase shifted and unshifted regions of the body.

With the reticle 100 of Figure 7 used in the apparatus of Figure 1, variation in the distance between the lens 44 and the wafer 34 causes the images 128, 130 of the square 112 and the square 122 to shift relative to each other as shown in Figures 8A, 8B and 8C. That is, with the distance between the lens 44 and wafer 34 providing proper focus, the images 128, 130 formed by the square 112 and the square 122 correspond to the positioning of the outlines 112, 122 on the reticle 100 forming these images, i.e., the image 130 of the square on the wafer 34 is centrally located within the image of the square 128 on the wafer 34 (Figure 8B). Decreasing the

distance between the lens 44 and the wafer 34 causes the image 128 formed by the outline 112 to shift leftward and upward while the image 130 formed by the outline 122 shifts rightward and downward (Figure 8A), indicating defocus. Increasing the distance between the lens 44 and wafer 34 causes the image 128 formed by the outline 112 to shift rightward and downwardly while the image 130 formed by the outline 122 shifts leftward and upward until the image 130 is centrally located within the image 128 (see Figure 8B), indicating that the image is in focus on the wafer 34. Further movement of the lens 44 and wafer 34 apart causes the image 128 formed by the outline 112 to further move downward and rightward, while the image 130 formed by the outline 122 further moves upward and leftward (Figure 8C), indicating defocus.

Similar to the above-described system, only a relatively coarse reading of focus is achievable. For example, the shift in positions of the images when going from Figure 8A to Figure 8C occurs over a range of 800 nm relative movement between the wafer 34 and lens 44. With device dimensions continually being reduced, there is a need to achieve a proper reading of focus within a much smaller range of lens-wafer relative movement, for example, 200 nm or less.

#### **SUMMARY OF THE INVENTION**

The present invention is an optical tool including a tool body that is transparent to light. Pluralities of opaque, parallel lines on the body form a first outline in the shape of square. Additional pluralities of opaque, parallel lines on the body form an outline in the shape of the square that is centrally located relative to and within the first-mentioned square. Each pair of adjacent lines has therebetween a first region which allows transmission of light therethrough without changing phase thereof, and a second region alongside the first region which allows transmission of light therethrough while shifting the phase thereof by 90°. The regions are laid out so that the images of the outlines formed by a lens on an object shift a substantial amount upon relative movement between the lens and object.

The present invention is better understood upon consideration of the detailed description below, in conjunction with the accompanying drawings. As will become readily apparent to those skilled in the art from the following description, there is shown and described an embodiment of this invention simply by way of the illustration of the best mode to carry out the invention. As will be realized, the invention is capable of other embodiments and its several details are capable of modifications and various obvious aspects, all without departing from the scope of the invention. Accordingly, the drawings and detailed description will be regarded as illustrative in nature and not as restrictive.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as said preferred mode of use, and further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an elevational view of a typical optical system used for patterning photoresist of a semiconductor wafer

Figure 2 is a plan view of a test focus monitor of the prior art;

Figure 3 is an elevational view of an optical system illustrating the use of the test focus monitor of Figure 2;

Figure 4 is an elevational view similar to that shown in Figure 3 again illustrating use of the test focus monitor of Figure 2;

Figure 5 is a plan view showing the paths of the shadows falling on the wafer as the optical system of Figures 3 and 4 is used;

Figure 6 includes Figures 6A-6F further illustrating use of the system of Figures 3 and 4;

Figure 7 is a plan view of another test focus monitor based on the prior art;

Figure 8 includes Figures 8A-8C illustrating use of the test focus monitor of Figure 7;

Figure 9 is a plan view of the present inventive test focused monitor;

Figure 10 includes Figures 10A and 10B which are sectional views taken along any of the lines 10A-10A and 10B-10B of Figure 9;

Figure 11 includes Figures 11A-11C which illustrate the use of the test focus monitor of Figure 9; and

Figure 12 includes Figure 12A and 12B, which are graphical representations showing the improvement in sensitivity of the present apparatus, as compared to the prior art.

**DETAILED DESCRIPTION**

Reference is now made in detail to specific embodiment of the present invention which illustrates the best mode presently contemplated by the inventors for practicing the invention.

Figure 9 and sectional views Figures 10A and 10B show the present test reticle 140 which is the subject of this invention. The present test reticle 140 includes a quartz body 142 that is transparent to light. The quartz body 142 has first, second, third and fourth sets of pluralities of parallel, opaque, for example, chrome lines 144, 146, 148, 150 on the body 142 which form an outline 152 in the configuration of a square. Between each adjacent pair of lines 144, 146, 148,

150 is a transparent portion 154 which includes first and second regions 156, 158 in side-by-side relation running the length of the adjacent lines, the region 156 providing transmission of light therethrough without change in phase thereof, the region 158, being recessed as described above, providing transmission of light therethrough while changing the phase thereof by  $90^\circ$ .

5       The quartz body also has fifth, sixth, seventh and eighth sets of pluralities of parallel, opaque, for example, chrome lines 160, 162, 164, 166 on the body 142 which form an outline 168 in the configuration of square, which is centrally positioned within the first-mentioned outline 152. Between each adjacent pair of lines 160, 162, 164, 166 is a transparent portion 154 which includes first and second regions 156, 158 in side-by-side relation running the length of  
10   the adjacent lines, the region 156 providing transmission of light therethrough without change in phase thereof, the region 158, being recessed as described above, providing transmission of light therethrough which changes the phase thereof by  $90^\circ$ .

15       The lines of the first, third, fifth and seventh sets 144, 148, 160, 164 thereof are parallel to each other, while the lines of the second, fourth, sixth and eighth sets 146, 150, 162, 166 thereof are parallel to each other.

      The present reticle 140 contains no regions which are the equivalent of the phase shifting regions 172 of the reticle of Figure 7.

      The positions of the first and second regions 156, 158 between the adjacent lines of the first set 144 thereof correspond to the positions of the first and second regions 156, 158 between  
20   the adjacent lines of the third set 148 thereof (see sectional view 10A-10A, Figure 10). Similarly, the positions of the first and second regions 156, 158 between the adjacent lines of the second set 146 thereof correspond to the positions of the first and second regions 156, 158 between the adjacent lines of the fourth set 150 thereof (see sectional view 10A-10A, Figure 10). The positions of the first and second regions 156, 158 between the adjacent lines of the fifth set  
25   160 thereof correspond to the positions of the first and second regions 156, 158 between adjacent lines of the seventh set 164 thereof, and the positions of the first and second regions 156, 158 between adjacent lines of the sixth set 162 thereof correspond to the positions of the first and second regions 156, 158 between adjacent lines of the eighth set 166 thereof (see sectional view 10B-10B, Figure 10).

30       The positions of the first and second regions 156, 158 between adjacent lines of the first set of lines 144 are reversed relative to the positions of the first and second regions 156, 158 between adjacent lines of the fifth set of lines 160, and the positions of the first and second regions 156, 158 between adjacent lines of the second set of lines 146 are reversed relative to the positions of the first and second regions 156, 158 between adjacent lines of the sixth set of lines  
35   162.

With the reticle 140 of Figure 9 used in the apparatus of Figure 1, variation in the distance between the lens 44 and the wafer 34 causes the images 180, 182 of the square 152 and the square 168 to shift relative to each other as shown in Figures 11A, 11B and 11C. That is, with the distance between the wafer 34 and the lens 44 providing proper focus, the images 180, 182 formed by the square 152 and the square 168 correspond to the positioning of the outlines 152, 168 on the reticle 140 forming those images, i.e., the image 182 of the square 168 on the wafer 34 is centrally located within the image 180 of the square 152 on the wafer 34 (Figure 11B). Decreasing the distance between the lens 44 and the wafer 34 causes the image 180 formed by the outline 152 to shift leftward and upward while the image 182 formed by the outline 168 shifts rightward and downward (Figure 11A), indicating defocus, all as described above. Increasing the distance between the lens 44 and wafer 34 causes the image 180 formed by the outline 152 to shift rightward and downward while the image 182 formed by the outline 168 shifts leftward and upward until the image 182 of the square 168 is centrally located within the image 180 of the square 152 (see Figure 11B, wherein the image is properly focused on the wafer 34). Further movement of the lens 44 and wafer 34 apart causes the image 180 formed by the outline 152 to further move downward and rightward, while the image 182 formed by the outline 168 further moves upward and leftward, indicating defocus.

However, the present apparatus is much more sensitive to changing distance between the lens 44 and the wafer 34 than is the previously described system. That is, the relative changing of the positions of the images 180, 182 when going from the state shown in Figure 11A to the state shown in Figure 11C is obtained through approximately 200 nm of relative movement between the lens 44 and wafer 34. This is to be compared with the patterns of shift of Figure 8, which appear to be similar to those shown in the present Figures 11A-11C, but are obtained over a range of approximately 500 nm of relative movement between the wafer 34 and lens 44. The increased sensitivity of the present embodiment is achieved by use of the multiple opaque lines as described above, each adjacent pair having therebetween a region which passes light therethrough without changing phase thereof, and a region which passes light therethrough while changing the phase thereof by 90°, all laid out as described above..

The improvement in sensitivity is clearly illustrated in the graphs shown on Figures 12A and 12B. As will be seen, the change in defocus is much greater for a given change in distance between the lens 44 and wafer 34 than in the prior art. It will thus be seen that a test reticle 140 that is greatly improved in sensitivity is herein provided.

The foregoing description of the embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Other modifications or variations are possible in light of the above teachings.

The embodiment was chosen and described to provide the best illustration of the principles of the invention and its practical application to thereby enable one of ordinary skill of the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention as determined by the appended claims when interpreted in accordance with the breadth to which they are fairly, legally and equitably entitled.